Comparison of Alexandria's Storm Design Criteria to Neighboring Jurisdictions

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Contents

Introduction

The City of Alexandria, Virginia has experienced repeated and increasingly frequent flooding events attributable to old infrastructure, inconsistent design criteria, and perhaps climate change. The purpose of the project at hand is to provide a program that, over a period of up to 5 years, will analyze storm sewer capacity issues, identify problem areas, develop and prioritize solutions, and provide support for public outreach and education.

The purpose of the first task is to review and propose revisions to the City's stormwater design criteria, through a series of four subtasks. This Technical Memorandum documents the results of subtask 1.1, whose purpose is to benchmark the City's stormwater design criteria with neighboring jurisdictions. The benchmarking is a part of the background research, along with new data analysis of rainfall records, leading to potential updates to City stormwater design criteria. The other three Task 1 subtasks that will inform the recommendations for updating the City's stormwater design criteria are as follows:

- Subtask 1.2 - Update Precipitation Frequency Results and Synthesize New IDF Curves
- Subtask 1.3 – Rainfall Frequency and Global Climate Change Model Options for Study Area
- Subtask 1.4 - Sea Level Rise

Approach

The approach to Task 1 is to review design criteria and rainfall intensity-duration-frequency (IDF) curves used in nearby communities. The review of design criteria included understanding design storms used (recurrence frequency and duration), design parameters (surcharge levels, gutter spread, etc.), and source data for IDF curves.

Purpose

This report presents and compares data collected from design standards currently used by the City of Alexandria and its neighboring jurisdictions. This is necessary to identify and measure key differences with City practices and establish a "benchmark" to reconcile differences and draft new City stormwater management (SWM) design criteria.

The design criteria cover three distinct areas—the design storm sewer pipes, catch basins, and SWM best management practices (BMP) facilities. The current design criteria for sewer pipes and catch basins use the Rational Formula. This formula is based on the use of instantaneous peak flows calculated from various rainfall intensities associated with storm frequencies and durations obtained from local IDF data, which historically have been presented graphically as curves. The IDF curves are the main focus of this report.

IDF Curves 5 – 60 Minutes

In highly urbanized, impervious areas such as Alexandria, the most common drainage design condition is found to depend on a short time of concentration (Tc). This leads to relatively high instantaneous rainfall intensities and large storm sewers. In this setting, individual land development projects often have times of concentration much shorter than 60 minutes and typically around 5 minutes. This is not only a factor for the storm sewer pipe sizing, but also the number and placement of storm drainage inlets or catch basins.

The 10-year, 5-minute intensity is the value with the most implications for site design. For the 2-, 10-, and 100-year storms from 5–60 minutes Tc, Alexandria uses a significantly higher intensity for design (approximately 30% higher) than all the neighboring jurisdictions.

For each of the design storms, the graph in Figure 1 shows three groupings. Alexandria is always alone and the highest, followed by Montgomery County and the District of Columbia close together, followed by the lower values for Arlington and Fairfax counties.

In 2005, VDOT updated its IDF values. The complete hydraulic design advisory that describes this change is presented in Appendix B. The new methodology for Arlington and Fairfax counties reduced their intensities in the 5– to 60-minute range. Previously, these intensities were more consistent with intensities from Montgomery County and the District. Another significant implication of the 2005 update is providing an equation instead of a graph for determining intensity values. The equation facilitates the use of spreadsheets and computer modeling, as well as eliminating the potential for differences in judgment in interpolating from nonlinear IDF graphs. It is recommended that the updated Alexandria intensity values calculated using the new analysis in a separate subtask of this contract be presented in the form of an equation with regression constants.

Alexandria's intensities are from 15 to 52 percent higher than the updated values for Arlington County. Note that the updated 100-year intensities for Arlington and Fairfax counties are not much higher than the 10-year intensities for Alexandria.

Having a much higher IDF leads to a local regulatory drive for larger pipes, which may not be necessary and could be counterproductive by increasing construction costs and the work areas required. It is important to reconcile the City design standard with surrounding jurisdictions and the City's latest SWM goals, so it may be useful to evaluate the adequacy of existing sewer piping that will be subjected to the City-wide stormwater model planned for this study. If the standard remains unchanged, it is likely that a greater amount of existing sewers may be classified as undersized and lead to a potentially incorrect conclusion that a large length of piping needs replacement.

Historically, Alexandria has been a leader in implementing many ultra-urban SWM design solutions. The design guidance from the late 1990s, however, discourages the use of low impact development (LID) / green infrastructure approaches by emphasizing direct connections to the storm system and an increase in pipe capacity based on higher storm intensities. The 1990's SWM design paradigm meets the requirements of treating first-flush quality, but allows for higher-intensity peak discharges and increased runoff volume to be passed rapidly downstream. Now that the design tools and approaches for LID/ green infrastructure in urban settings are more developed and more commonly applied, we recommend the City consider adapting the design guidelines to encourage rather than discourage the use of integrated practices with temporary storage and slow release to the storm system. A revision of the design criteria to a lower 10-year intensity, if the analysis produces results similar to the 2005 values for Arlington and Fairfax counties, will encourage more LID /green infrastructure integrated practices. The benefit will arise in providing better ecosystem results downstream.

The modeling proposed in this study may take into account and incorporate this new LID strategy and look for more stormwater volume storage within the sewer system as a benefit. A key point is to find locations where occasional flooding may be tolerated as a way to mitigate peak flows and required sewer pipe replacement projects.

IDF Curves 1 – 24 Hours

The longer times of concentration are also significant from a benchmarking perspective with climatology data. The 200-acre upper limit of the Rational Method typically requires calculation by another methodology prior to reaching a time of concentration of more than 1 hour. However, because rainfall data are recorded in increments of 15 minutes or 1 hour, the intensities for short times of concentration are mathematically derived from the data.

On the graph in Figure 3, Alexandria's values are high at 1 to 3 hours and become consistent with Montgomery County and the District from 6 to 24 hours, followed by values more consistent with Arlington and Fairfax counties on the 2-year and 10-year storms. The updated values for Arlington and Fairfax counties become much higher than other jurisdictions on the 100-year intensities for the longer-duration storms.

Similar to the argument for reducing the IDF for the shorter times of concentration, times of concentration of more than 1 hour generally apply to regional SWM and defined public projects intended to mitigate peak flows within existing storm sewer systems by siting stormwater holding or detention facilities. This approach needs to be reconciled with surrounding jurisdictions so that the design requirements and facility sizes are economically consistent with other areas and the public expenditure is justified.

Inlet and Pipe Sizing

Storm pipe sizing and maximum gutter spread criteria are generally consistent across the jurisdictions. However, Alexandria uses an intensity rate of 9 inches per hour in the calculation, which is more than double the VDOT rate. For comparison, in Alexandria, 9 inches per hour is a 10-year storm and in the District would be the 50-year storm. The implication therefore is a need for more inlets closer together and/or larger inlets in Alexandria than in other jurisdictions. Although perhaps difficult to quantify, the temporary ponding outside of storm inlets attenuates the peak flow rate in the storm pipes. Therefore, providing more inlets in the city will increase the peak inflow rate into the storm pipe system.

In Alexandria, where the needs of pedestrians are more of a concern than other jurisdictions with primarily vehicle-only roads, a higher design standard for inlets is warranted. No change to the design criteria is recommended.

SWM/BMP Sizing

SWM quantity control criteria are fairly consistent across the jurisdictions. Alexandria's higher peak intensities result in requiring larger dry storage volumes to attenuate to pre-development peak flow rates. Note that obtaining the Leadership in Energy and Environmental Design (LEED) quantity control credit requires managing the increase in runoff volume as well as the increase in peak flow rates. Controlling increased volumes requires infiltration, plant uptake, or onsite reuse, such as for irrigation or toilet flushing.

For BMP water quality volume (WQV) required to be treated, the jurisdictions fall into two general categories. Alexandria, the District, and the current version of the *Virginia Stormwater Management Handbook* require a WQV of 0.5 inch of runoff from impervious surfaces. The Maryland Department of the Environment and LEED standards require a WQV of 1 inch. The update of the Virginia handbook, due out late 2009, will include a revision to 0.9 inch. It is also noteworthy that the revision includes incorporation of the Runoff Reduction Method calculation, developed by the Center for Watershed Protection and the Chesapeake Stormwater Network. This calculation rewards directing runoff to vegetated surfaces with a reduction in the post-developed peaks and volumes that require quantity and quality control. Although there are fewer opportunities to use vegetated surfaces in a highly urban setting, it is recommend that the City investigate this method as a tool for encouraging green space, disconnecting impervious areas, and reducing the use of potable water for landscaping irrigation.

This report recommends that the City adopt the forthcoming 2009 update to the *Virginia Stormwater Management Handbook* as the BMP sizing criteria. The diversion of an additional 0.4 inch of runoff volume to water quality treatment translates to a 6-percent reduction in the 5–minute, 10-year peak flow rate from the site, if the new study intensity is comparable to the 2005 Arlington and Fairfax counties' values.

References

City of Alexandria

City IDF chart based on TP-40 1941-1969

ESI course outline *Alexandria Land Development Education Program* (1999)

Arlington County

IDF values calculated with regression constants and equation I=B/(D+Tc)^E from *VDOT Hydraulic Design Advisory, HDA 05-03,* dated June 2005, rev 7/26/06. Based on NOAA ATLAS 14. Supersedes previous curves based on TP-40 and HYDRO 35.

IDF curve from *VDOT Drainage Manual Appendix 6B-4* (Curve table values used instead of calculation by previous regression constants.)

Fairfax County

IDF values calculated with regression constants and equation I=B/(D+Tc)^E from *VDOT Hydraulic Design Advisory, HDA 05-03,*dDated June 2005, rev 7/26/06. Based on NOAA ATLAS 14. Supersedes previous curves based on TP-40 and HYDRO 35.

IDF curve from Fairfax County *Public Facilities Manual*, plate # 3-6

VDOT. 2002. *VDOT Drainage Manual*. Adopted April 2002.

Montgomery County

Maryland State Highway Administration. *Highway Drainage Manual*. IDF based on TP-40 and HYDRO 35.

Maryland Department of the Environment. 2000. *Maryland Stormwater Design Manual*, October.

District of Columbia

DC Department of Health, Watershed Protection Division. *Stormwater Management Guidelines.* 2003. Produced by the Center for Watershed Protection.

District of Columbia Department of Transportation*. Design & Engineering Manual*, Chapter 33.

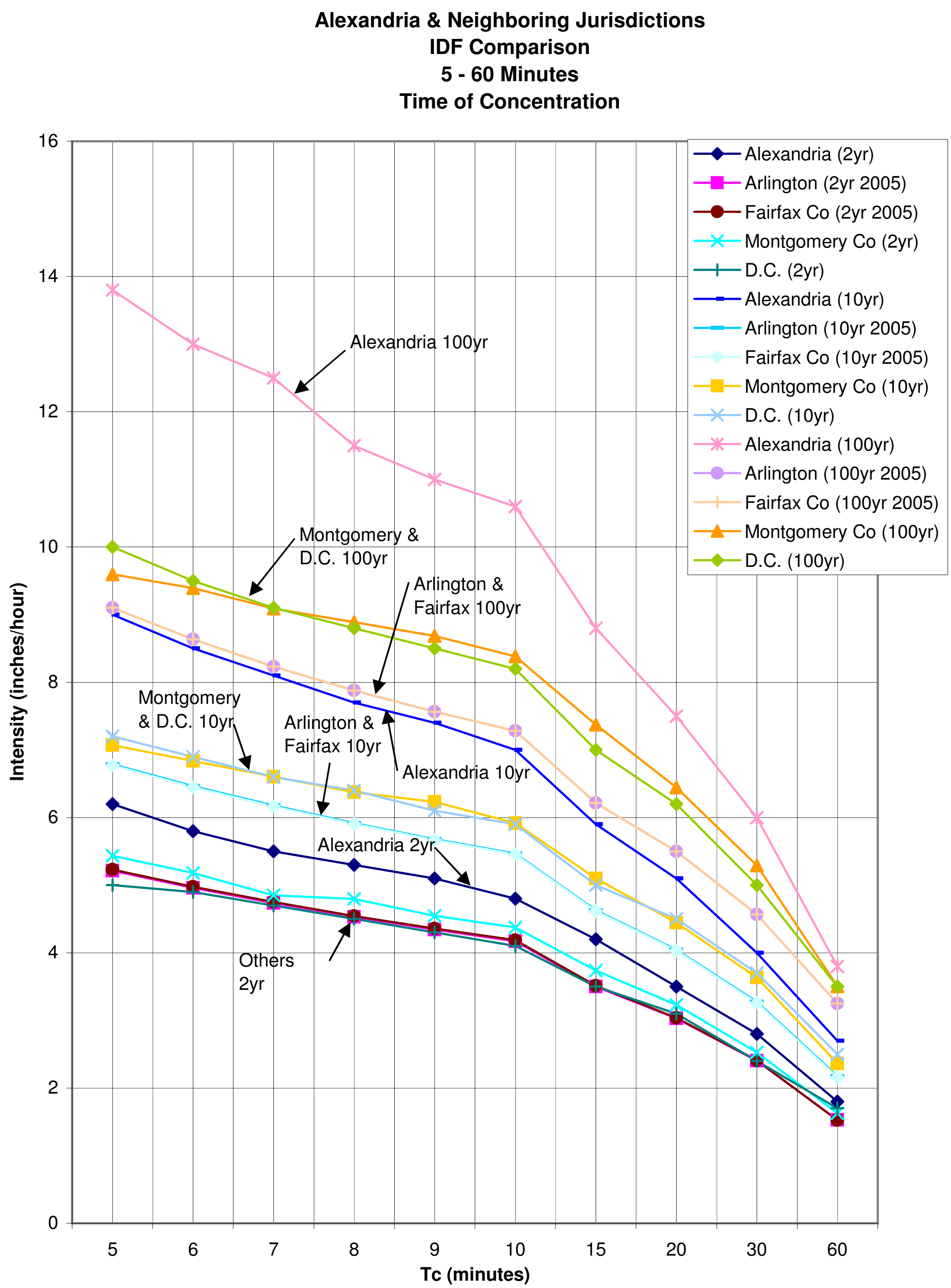
Additional SWM/BMP References

1999. *Virginia Stormwater Management Handbook*.

To be published 2009. *Virginia Stormwater Management Handbook*. Excerpts provided for comment.

U.S. Green Building Council. *LEED Reference Manual*, version 2.2.

Figures



Alexandria & Neighboring Jurisdictions
IDF Comparison
5 - 60 Minutes
Time of Concentration
Intensity (inches/hour)
Tc (minutes)
Alexandria (2yr)
Arlington (2yr 2005)
Fairfax Co (2yr 2005)
Montgomery Co (2yr)
D.C. (2yr)
Alexandria (10yr)
Arlington (10yr 2005)
Fairfax Co (10yr 2005)
Montgomery Co (10yr)
D.C. (10yr)
Alexandria (100yr)
Arlington (100yr 2005)
Fairfax Co (100yr 2005)
Montgomery Co (100yr)
D.C. (100yr)
Alexandria 100yr
Montgomery & D.C. 100yr
Arlington & Fairfax 100yr
Montgomery & D.C. 10yr
Arlington & Fairfax 10yr
Alexandria 10yr
Alexandria 2yr
Others 2yr

Figure 1

Rational Method				Alexandria & Neighboring Jurisdictions IDF Comparison									
2-year	regression constants			Minutes									
Jurisdiction	B	D	E	5	6	7	8	9	10	15	20	30	60
Alexandria	-	-	-	**6.2**	**5.8**	**5.5**	**5.3**	**5.1**	**4.8**	**4.2**	**3.5**	**2.8**	**1.8**
Arlington (VDOT HDA 05-03)	*52.73*	*11.25*	*0.83*	*5.21*	*4.96*	*4.73*	*4.53*	*4.34*	*4.17*	*3.50*	*3.03*	*2.41*	*1.53*
Arlington (previous VDOT chart)	-	-	-	5.5	5.3	5.0	4.75	4.5	4.3	3.55	3.05	2.4	1.55
Fairfax Co (VDOT HDA 05-03)	*55.09*	*11.5*	*0.84*	*5.23*	*4.98*	*4.75*	*4.54*	*4.36*	*4.19*	*3.51*	*3.04*	*2.41*	*1.53*
Fairfax Co (PFM 2001)	-	-	-	5.0	4.7	4.5	4.30	4.15	4.0	3.4	3.1	2.5	1.5
Montgomery Co	-	-	-	5.43	5.18	4.85	4.80	4.55	4.37	3.74	3.23	2.53	1.63
D.C. (Table A-2)	-	-	-	5.28	-	-	-	-	4.44	3.83	3.36	2.7	1.7
D.C. (Figure A-1)	-	-	-	5.0	4.9	4.7	4.5	4.3	4.1	3.5	3.1	2.4	1.7
Alexandria compared to Arlington 2005				**119%**	**117%**	**116%**	**117%**	**117%**	**115%**	**120%**	**116%**	**116%**	**118%**

10-year	regression constants			Minutes									
Jurisdiction	B	D	E	5	6	7	8	9	10	15	20	30	60
Alexandria	-	-	-	**9.0**	**8.5**	**8.1**	**7.7**	**7.4**	**7.0**	**5.9**	**5.1**	**4.0**	**2.7**
Arlington (VDOT HDA 05-03)	*45.98*	*9.25*	*0.72*	*6.79*	*6.47*	*6.18*	*5.92*	*5.68*	*5.47*	*4.63*	*4.05*	*3.27*	*2.18*
Arlington (previous VDOT chart)	-	-	-	7.2	6.85	6.6	6.4	6.2	5.8	5.0	4.3	3.45	2.25
Fairfax Co (VDOT HDA 05-03)	*47.7*	*9.5*	*0.73*	*6.77*	*6.45*	*6.16*	*5.90*	*5.67*	*5.45*	*4.62*	*4.03*	*3.26*	*2.16*
Fairfax Co (PFM 2001)	-	-	-	7.0	6.8	6.5	6.1	5.8	5.5	4.8	4.2	3.5	2.5
Montgomery Co	-	-	-	7.07	6.84	6.61	6.37	6.23	5.92	5.10	4.44	3.64	2.36
D.C. (Table A-2)	-	-	-	7.34	-	-	-	-	6.11	5.27	4.65	3.79	2.51
D.C. (Figure A-1)	-	-	-	7.2	6.9	6.6	6.4	6.1	5.9	5.0	4.5	3.7	2.5
Alexandria compared to Arlington 2005				**133%**	**131%**	**131%**	**130%**	**130%**	**128%**	**127%**	**126%**	**122%**	**124%**

100-year	regression constants			Minutes									
Jurisdiction	B	D	E	5	6	7	8	9	10	15	20	30	60
Alexandria	-	-	-	**13.8**	**13.0**	**12.5**	**11.5**	**11.0**	**10.6**	**8.8**	**7.5**	**6.0**	**3.8**
Arlington (VDOT HDA 05-03)	*32.29*	*5*	*0.55*	*9.10*	*8.64*	*8.23*	*7.88*	*7.56*	*7.28*	*6.22*	*5.50*	*4.57*	*3.25*
Arlington (previous VDOT chart)	-	-	-	9.60	9.45	9.25	8.80	8.60	8.40	7.25	6.35	5.20	3.30
Fairfax Co (VDOT HDA 05-03)	*32.29*	*5*	*0.55*	*9.10*	*8.64*	*8.23*	*7.88*	*7.56*	*7.28*	*6.22*	*5.50*	*4.57*	*3.25*
Fairfax Co (PFM 2001)	-	-	-	10.0	9.5	9.0	8.5	8.2	7.9	7.0	6.3	5.0	3.3
Montgomery Co	-	-	-	9.60	9.39	9.09	8.89	8.69	8.38	7.37	6.44	5.29	3.50
D.C. (Table A-2)	-	-	-	8.89	-	-	-	-	7.9	6.42	5.59	4.65	3.39
D.C. (Figure A-1)	-	-	-	10.0	9.5	9.1	8.8	8.5	8.2	7.0	6.2	5.0	3.5
Alexandria compared to Arlington 2005				**152%**	**151%**	**152%**	**146%**	**145%**	**146%**	**142%**	**136%**	**131%**	**117%**

Figure 2

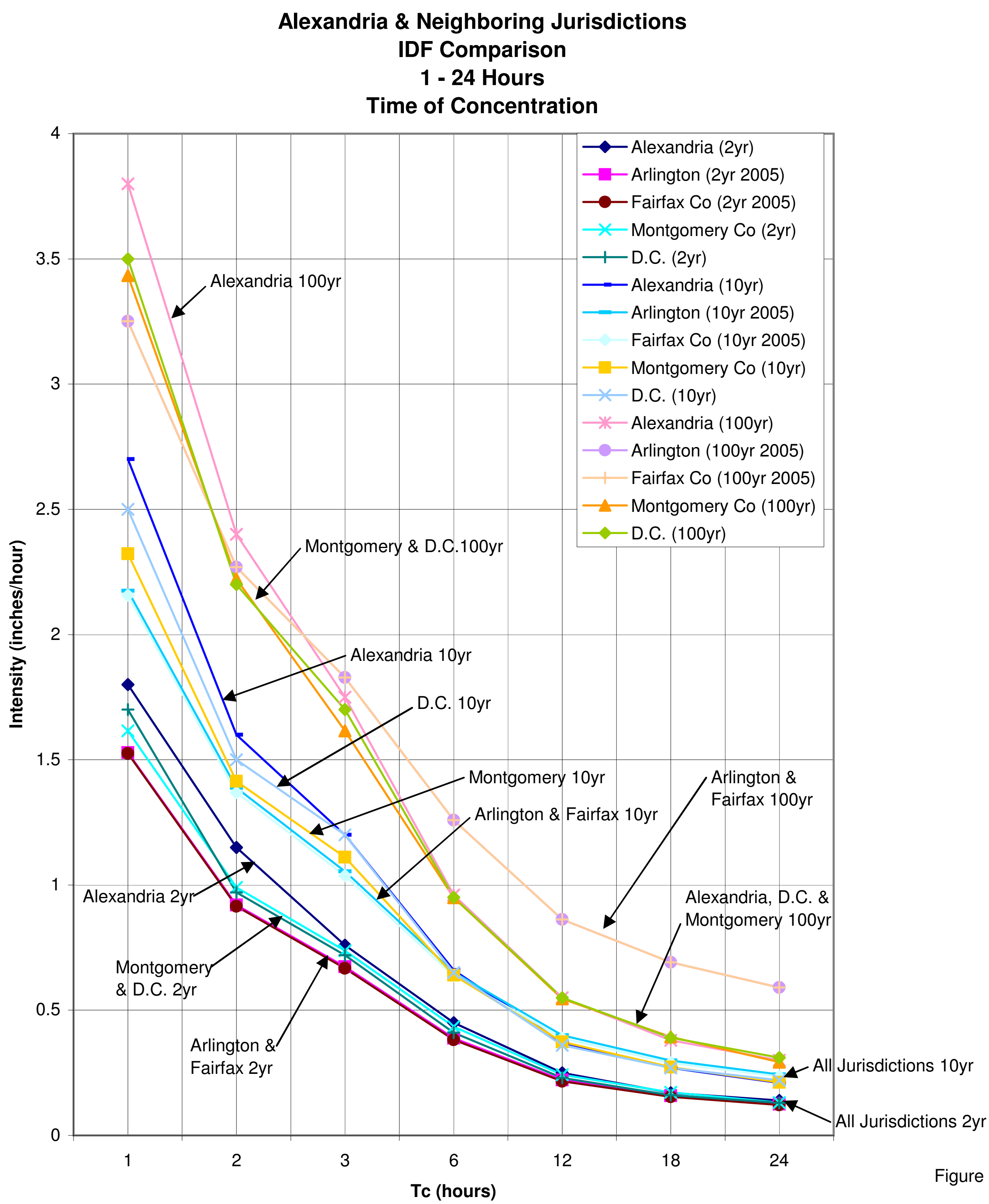

Alexandria & Neighboring Jurisdictions
IDF Comparison
1 - 24 Hours
Time of Concentration
Intensity (inches/hour)
Tc (hours)
Alexandria (2yr)
Arlington (2yr 2005)
Fairfax Co (2yr 2005)
Montgomery Co (2yr)
D.C. (2yr)
Alexandria (10yr)
Arlington (10yr 2005)
Fairfax Co (10yr 2005)
Montgomery Co (10yr)
D.C. (10yr)
Alexandria (100yr)
Arlington (100yr 2005)
Fairfax Co (100yr 2005)
Montgomery Co (100yr)
D.C. (100yr)
Alexandria 100yr
Montgomery & D.C.100yr
Alexandria 10yr
D.C. 10yr
Montgomery 10yr
Arlington & Fairfax 10yr
Arlington & Fairfax 100yr
Alexandria, D.C. & Montgomery 100yr
Alexandria 2yr
Montgomery & D.C. 2yr
Arlington & Fairfax 2yr
All Jurisdictions 10yr
All Jurisdictions 2yr
0
0.5
1
1.5
2
2.5
3
3.5
4
1
2
3
6
12
18
24

Figure 3

Rational Method				**Alexandria & Neighboring Jurisdictions IDF Comparison**						
2-year	regression constants			Hours						
Jurisdiction	B	D	E	1	2	3	6	12	18	24
Alexandria	**-**	**-**	**-**	**1.8**	**1.15**	**0.76**	**0.45**	**0.25**	**0.17**	**0.14**
Arlington (VDOT HDA 05-03)	*52.73*	*11.25*	*0.83*	*1.53*	*0.92*	*0.67*	*0.39*	*0.22*	*0.16*	*0.13*
Fairfax Co (VDOT HDA 05-03)	*55.09*	*11.5*	*0.84*	*1.53*	*0.91*	*0.67*	*0.38*	*0.22*	*0.15*	*0.12*
Montgomery Co	-	-	-	1.6	1.0	0.74	0.43	0.24	0.17	0.13
D.C. (Table A-2)	-	-	-	1.7	0.97	0.68	0.35	0.18		0.09
D.C. (Figure A-1)	-	-	-	1.7	0.97	0.72	0.41	0.23	0.16	0.13
Alexandria compared to Arlington 2005				**118%**	**125%**	**113%**	**116%**	**113%**	**107%**	**112%**

10-year	regression constants			Hours						
Jurisdiction	B	D	E	1	2	3	6	12	18	24
Alexandria	**-**	**-**	**-**	**2.7**	**1.6**	**1.2**	**0.66**	**0.37**	**0.27**	**0.21**
Arlington (VDOT HDA 05-03)	*45.98*	*9.25*	*0.72*	*2.18*	*1.39*	*1.05*	*0.65*	*0.40*	*0.30*	*0.24*
Fairfax Co (VDOT HDA 05-03)	*47.7*	*9.5*	*0.73*	*2.16*	*1.37*	*1.04*	*0.64*	*0.39*	*0.29*	*0.23*
Montgomery Co	-	-	-	2.3	1.4	1.11	0.64	0.37	0.27	0.21
D.C. (Table A-2)	-	-	-	2.51	1.57	1.17	0.69	0.40		0.23
D.C. (Figure A-1)	-	-	-	2.5	1.5	1.20	0.65	0.36	0.27	0.22
Alexandria compared to Arlington 2005				**124%**	**115%**	**114%**	**101%**	**93%**	**90%**	**86%**

100-year	regression constants			Hours						
Jurisdiction	B	D	E	1	2	3	6	12	18	24
Alexandria	**-**	**-**	**-**	**3.8**	**2.4**	**1.75**	**0.96**	**0.55**	**0.38**	**0.30**
Arlington (VDOT HDA 05-03)	*32.29*	*5*	*0.55*	*3.25*	*2.27*	*1.83*	*1.26*	*0.86*	*0.69*	*0.59*
Fairfax Co (VDOT HDA 05-03)	*32.29*	*5*	*0.55*	*3.25*	*2.27*	*1.83*	*1.26*	*0.86*	*0.69*	*0.59*
Montgomery Co	-	-	-	3.43	2.22	1.62	0.95	0.55	0.39	0.29
D.C. (Table A-2)	-	-	-	3.39	-	-	-	-	-	-
D.C. (Figure A-1)	-	-	-	3.5	2.2	1.7	0.95	0.55	0.39	0.31
Alexandria compared to Arlington 2005				**117%**	**106%**	**96%**	**76%**	**64%**	**55%**	**51%**

Figure 4

Comparison of Sizing Criteria for Storm Inlets and Pipes			
Jurisdiction	Intensity for Inlets & Gutter Spread	Max Gutter Spread for Inlets Spacing	Pipes Material & Design Storm
Alexandria	**Always 5 min Tc, 10-yr = 9.0 in/hr**	**subdivision 10 ft; collectors 6 ft**	**cl.IV RCP under pavement or in easements, 10 yr design**
VDOT	4 in/hr	8 ft	cl. III RCP typical, local/collector/minor arterial = 10 yr, principal arterial = 25 yr, interstate = 50-yr, depressed section of interstate 100 yr
MDSHA	2yr, 5min TC = 5.43 in/hr for Montgomery Co	8 ft	10 yr full flow, 25 yr HGL below rims, 100 yr HGL below top of curb
DDOT	15yr, 5 min Tc= 7.56 in/hr	6 ft	Local streets 15 yr flowing full, Interstates 25 yr, depressed & underpasses & road sags 50 yr; contributing area is only roadway & directly connected sidewalk

Figure 5

Comparison of SWM & BMP Sizing Criteria

Jurisdiction	SWM Quantity Control	Water Quality Volume	WQ flow thru rate (cfs)
Alexandria	**Post- Q2, Q10 less than Pre-; Braddock/West area req's 10% attentuation of Pre- Q2, Q10; Four Mile Run zone A&B also req's Post- Q100 less than Pre-**	**CBPA performance method: New Development Post- Phosphorus loading less than Pre-; Redevelopment 10% reduction of Pre-; WQV = 0.5 inches/ imperv area = 1816 CF/ Ia**	**1.75**
Virginia Stormwater Management Handbook 1999-2009	Post- Q1, Q10 less than Pre-	0.5 inch x imperv area = 1815 CF/ Ia	0.26 cfs = peak flow rate of 0.7" rain producing 0.5" runoff
Virginia Stormwater Management Handbook 2009 Update - not yet final	Post- Q1, Q10 not exceed Pre-. Runoff Reduction Method. Up to 30% volume reduction for vegetated conveyance	0.9 inch x impervious area = 3267 CF / Ia Up to 30% reduction in treatment volume if use vegetated conveyance	
MDE	Infiltration of ground water Recharge Volume; 24hr extended detention of Q1; Post- Q10 less than Pre-	1 inch = 3630 CF / Ia	
D.C.	Post- Q2 & Q15 less than Pre-; Post- Q100 less than Pre- if in flood hazard watershed	Streets & Parking: 0.5" = 1816 CF / Ia; Roofs Sidewalks & Pedestrian Plazas: 0.3" = 1090 CF / Ia	
LEED	Post- Q1, Q2 peaks & VOLUME less than Pre-. Volume control requires infiltration, plant uptake, or reuse; Redevelopment of sites >50% Imperv req's 25% decrease in 2-yr 24hr volume.	1 inch = 3630 CF / Ia	

Figure 6

Appendix A
Alexandria, Montgomery County, and District of Columbia IDFs

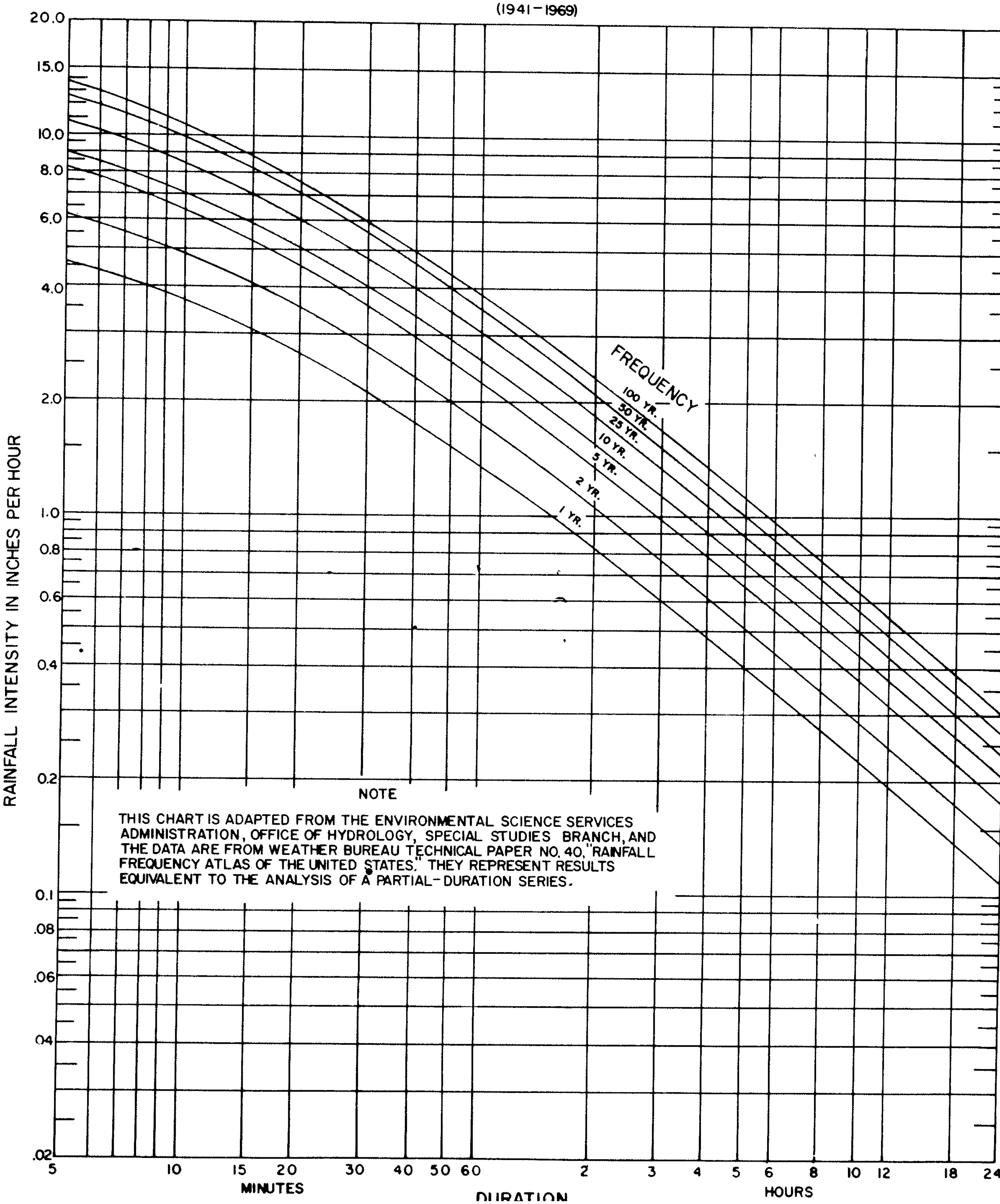
CITY OF ALEXANDRIA

RAINFALL INTENSITY — DURATION — FREQUENCY CURVES

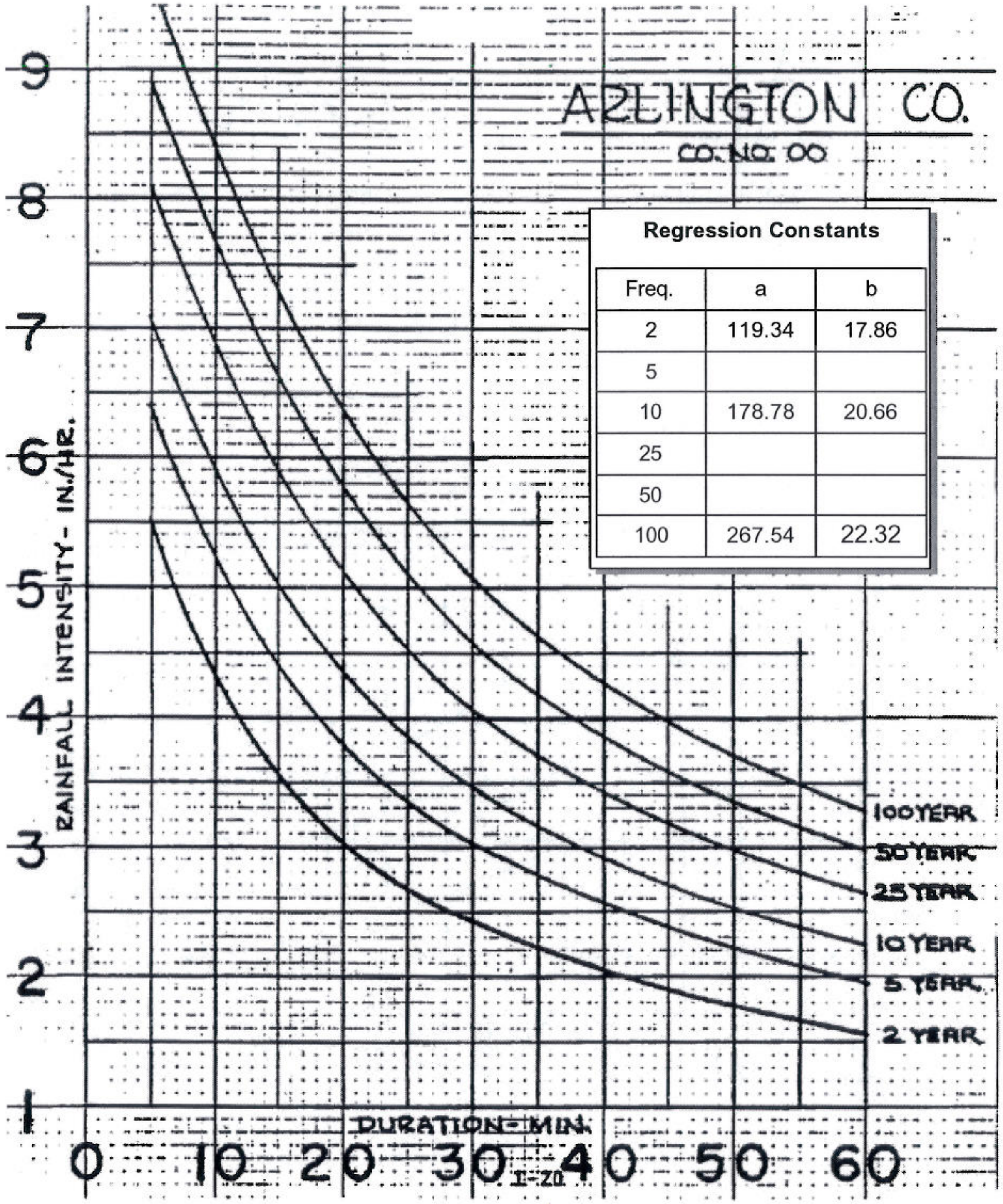
WASHINGTON NATIONAL AIRPORT

38°51' 77°03'

(1941 – 1969)



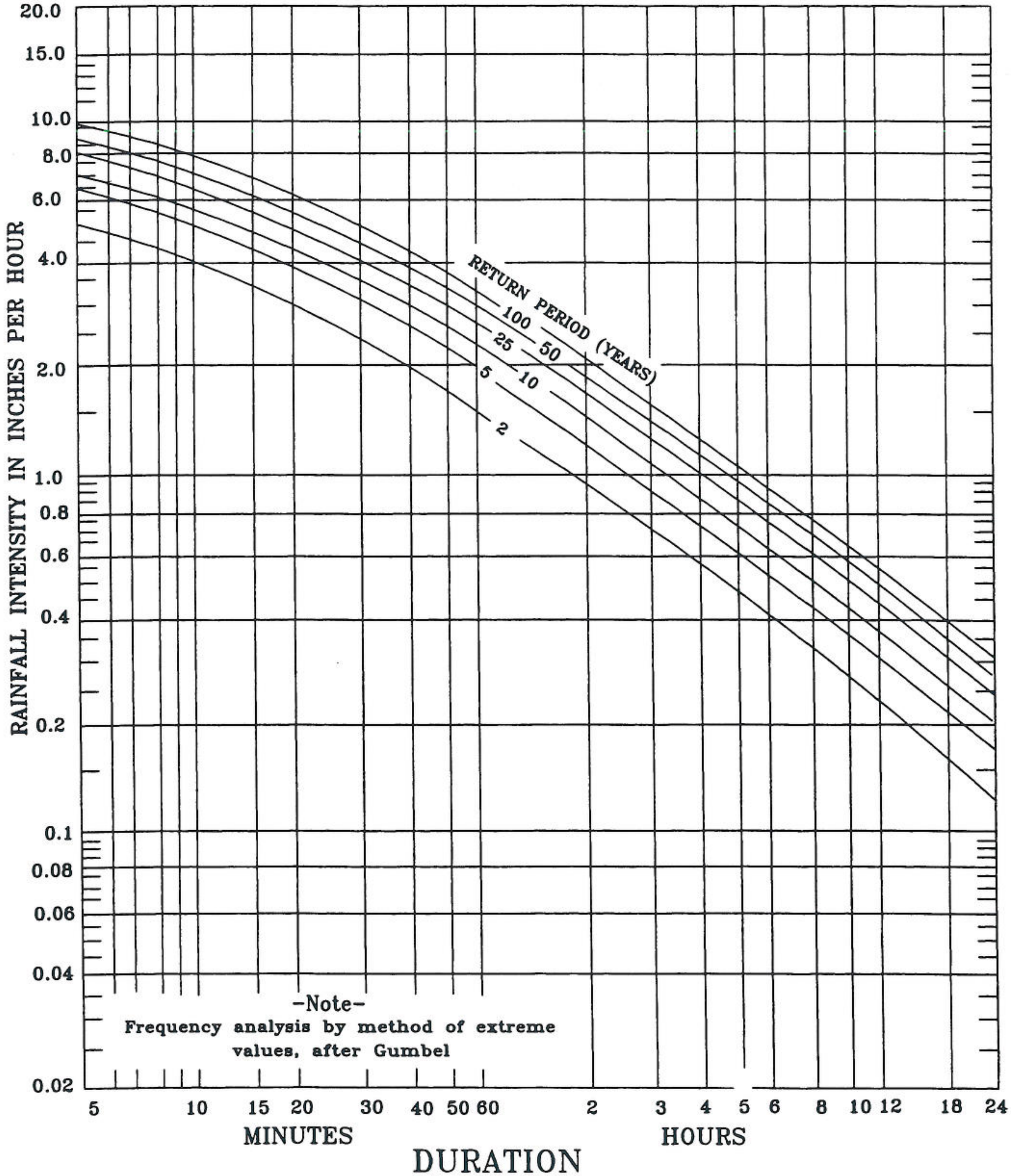
Appendix 6B-4 Rainfall Intensity Inches Per Hour
Arlington Co.



Regression Constants

Freq.	a	b
2	119.34	17.86
5		
10	178.78	20.66
25		
50		
100	267.54	22.32

Source:
Regression Constants from Virginia Stormwater Management Handbook, 1st Ed., Vol. II, 1999



Ref. Sec. 6-0803.2, 6-1305.10A(1) Rev. 1-00	INTENSITY DURATION FREQUENCY CURVES	PLATE NO.	STD. NO.
		3-6	

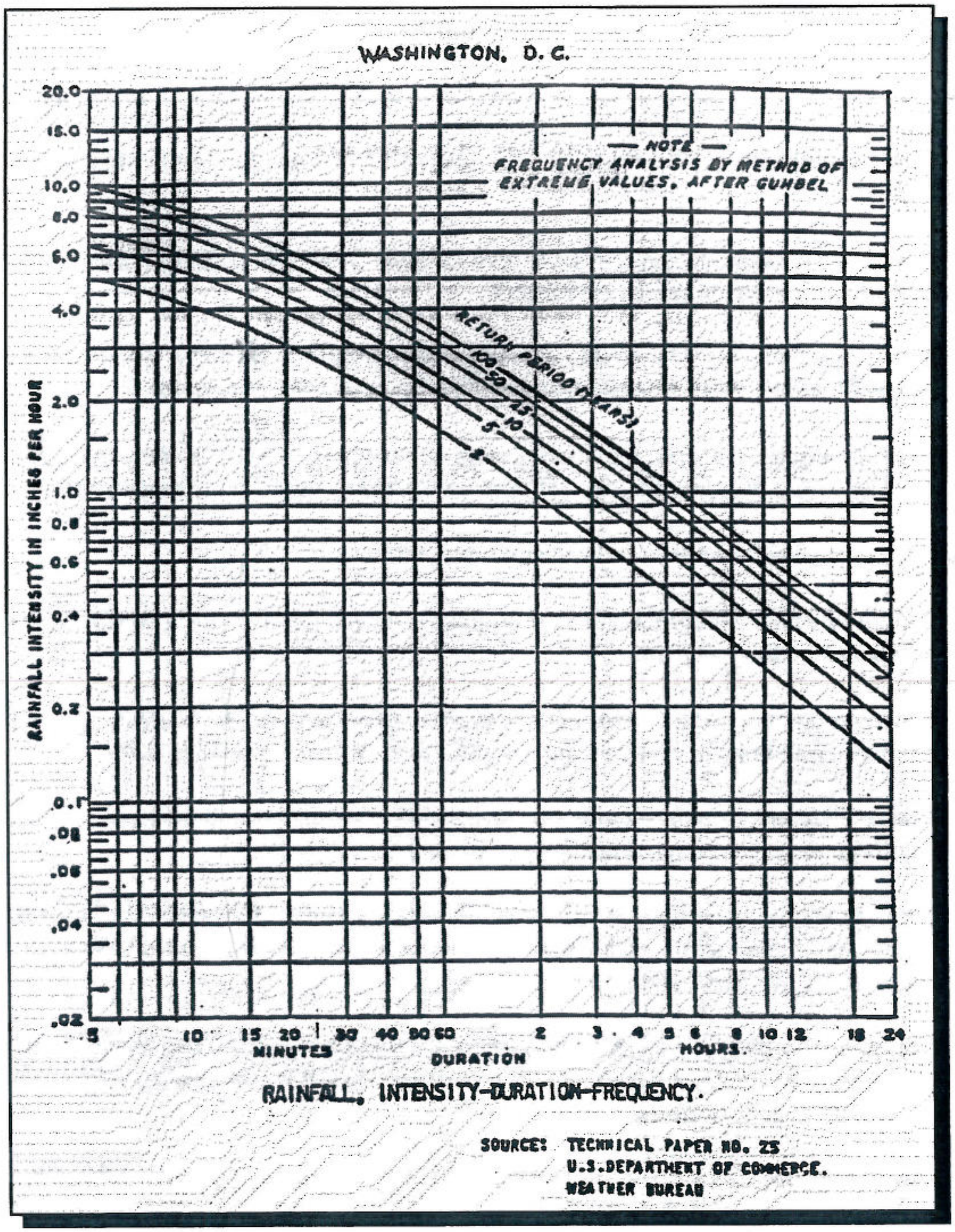
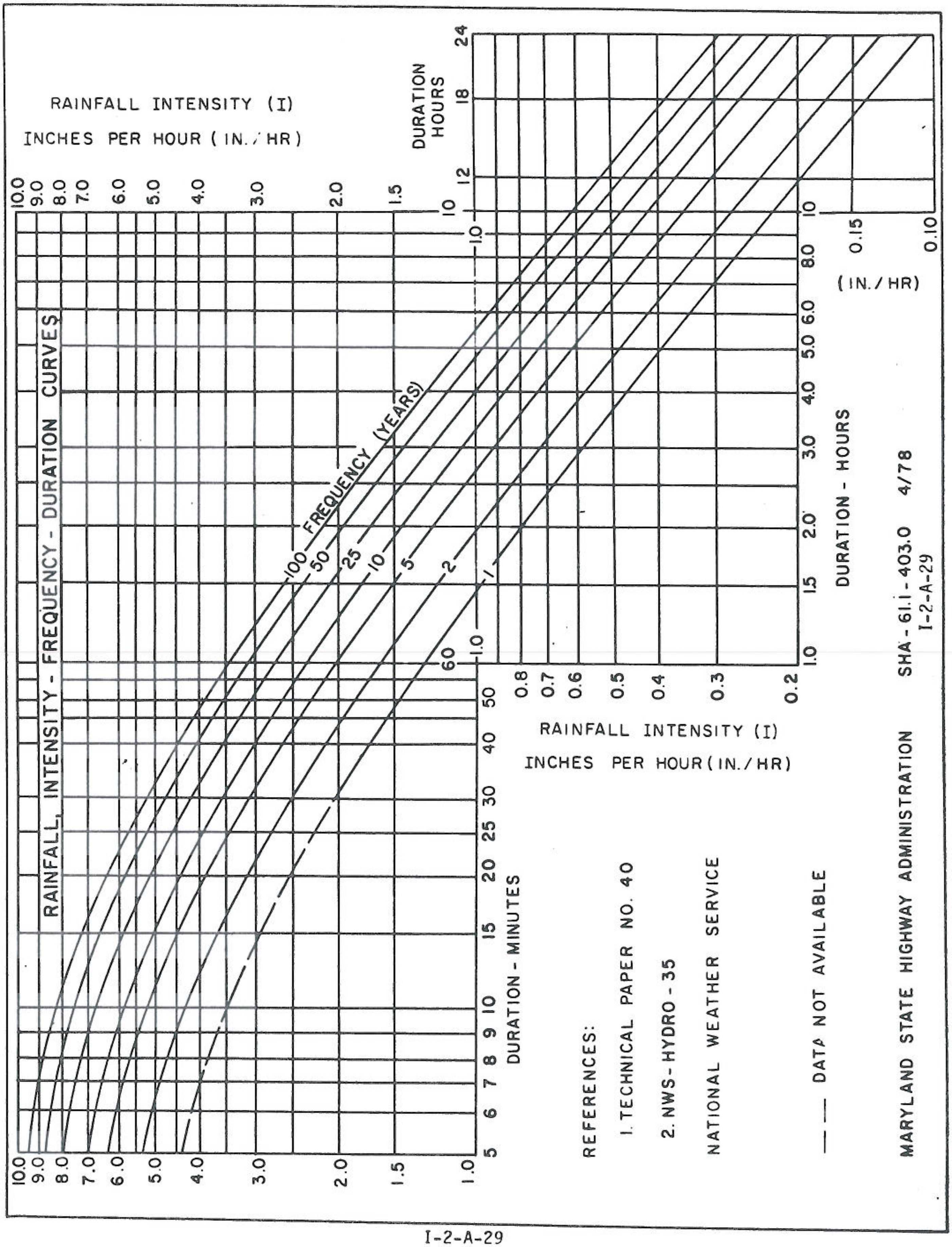


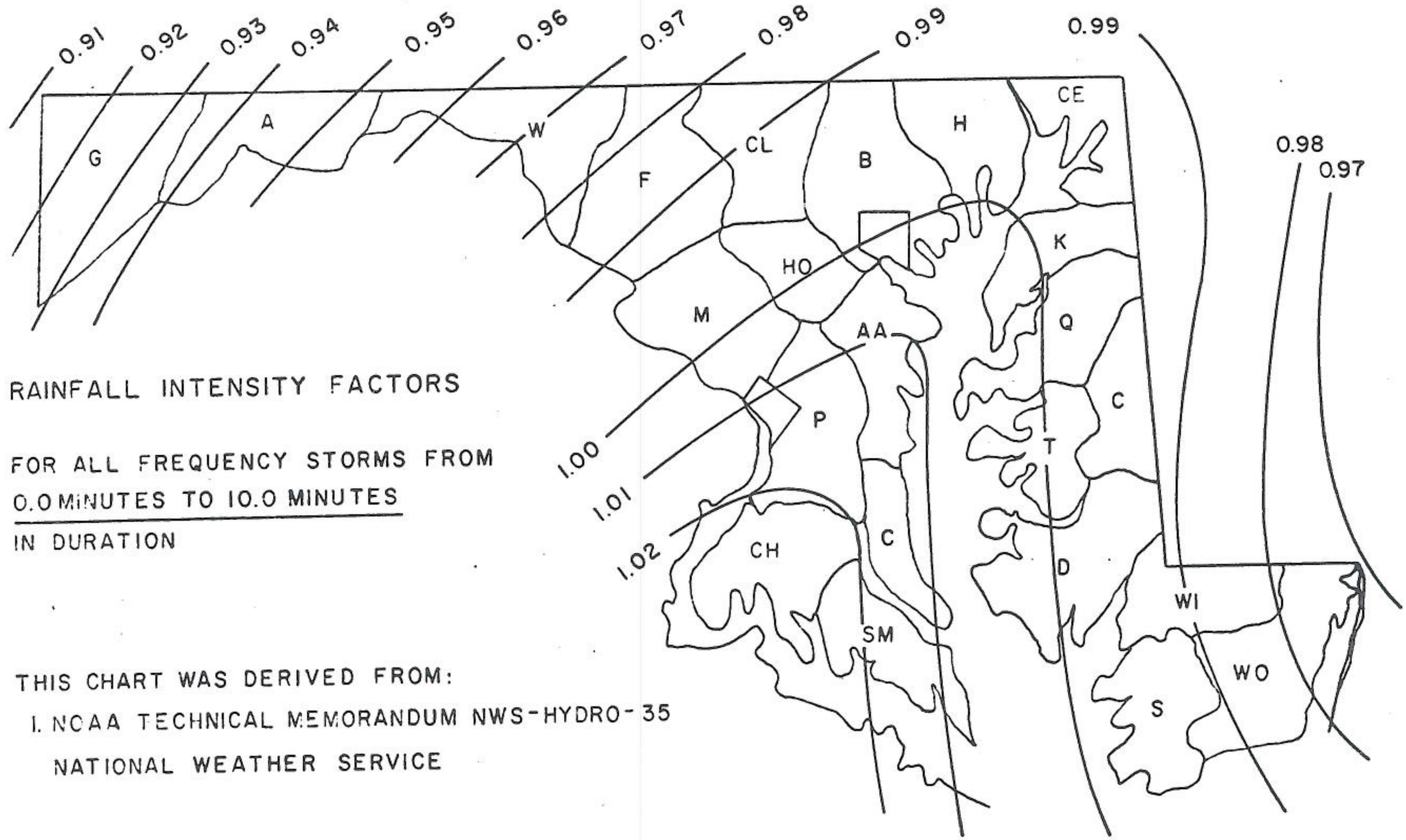
Figure A.1 District of Columbia Rainfall Intensity - Duration - Frequency Curve

Table A.2 Depth-Duration-Intensity-Frequency Rainfall Values for the District of Columbia

	1 Year		2 Year		5 Year		10 Year		15 Year		20 Year		25 Year		50 Year		100 Year	
Time (min)	d	i	d	i	d	i	d	i	d	i	d	i	d	i	d	i	d	i
5	0.38	4.60	0.44	5.28	0.54	6.42	0.61	7.34	0.63	7.56	0.64	7.63	0.66	7.93	0.72	8.61	0.74	8.89
10	0.65	3.88	0.74	4.44	0.89	5.34	1.02	6.11	1.05	6.30	1.06	6.36	1.10	6.64	1.20	7.20	1.25	7.90
15	0.83	3.32	0.96	3.83	1.15	4.59	1.32	5.27	1.36	5.44	1.38	5.50	1.43	5.72	1.54	6.14	1.61	6.42
20	0.97	2.91	1.12	3.36	1.35	4.04	1.55	4.65	1.61	4.82	1.63	4.88	1.69	5.08	1.78	5.35	1.86	5.59
30	1.13	2.26	1.35	2.70	1.64	3.27	1.90	3.79	1.97	3.95	2.02	4.03	2.10	4.19	2.24	4.49	2.32	4.65
45	1.29	1.72	1.57	2.09	1.93	2.57	2.25	3.01	2.37	3.16	2.44	3.25	2.54	3.38	2.83	3.77	2.96	3.94
60	1.38	1.38	1.70	1.70	2.13	2.13	2.51	2.51	2.66	2.66	2.76	2.76	2.87	2.87	3.22	3.22	3.39	3.39
80	1.49	1.12	1.81	1.36	2.33	1.75	2.77	2.08	2.96	2.22	3.10	2.32	3.22	2.42				
100	1.55	0.93	1.89	1.13	2.48	1.49	2.98	1.79	3.20	1.92	3.37	2.02	3.51	2.10				
120	1.58	0.79	1.94	0.97	2.60	1.30	3.14	1.57	3.40	1.70	3.61	1.80	3.75	1.87				
150	1.65	0.66	2.00	0.80	2.75	1.10	3.34	1.34	3.65	1.46	3.90	1.56	4.06	1.62				
180	1.68	0.56	2.04	0.68	2.86	0.95	3.50	1.17	3.87	1.29	4.16	1.39	4.32	1.44				
360			2.13	0.35	3.29	0.55	4.15	0.69	4.68	0.78	5.23	0.87	5.43	0.91				
720			2.16	0.18	3.73	0.31	4.84	0.40	5.64	0.47	6.49	0.54	6.75	0.56				
1440			2.17	0.09	4.18	0.17	5.62	0.23	6.79	0.28	8.04	0.34	8.35	0.35				

Notes: t = time in minutes
d = rainfall depth in inches
i = rainfall intensity in inches per hour
In general, i = (60 * d) / t

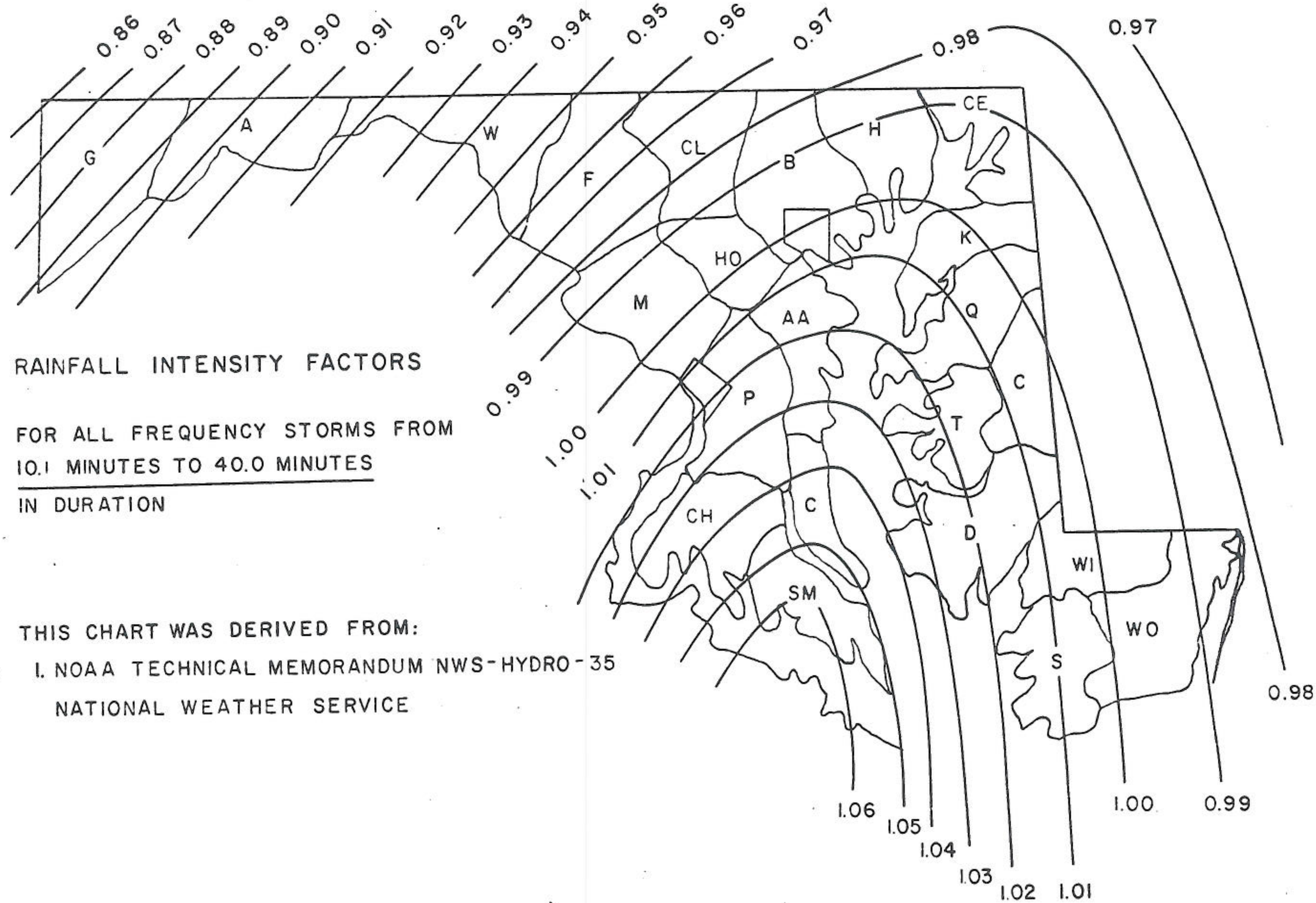

RAINFALL, INTENSITY - FREQUENCY - DURATION CURVES
RAINFALL INTENSITY (I)
INCHES PER HOUR (IN./HR)
DURATION HOURS
DURATION - MINUTES
DURATION - HOURS
(IN./HR)
FREQUENCY (YEARS)
100
50
25
10
5
2
1
REFERENCES:
1. TECHNICAL PAPER NO. 40
2. NWS-HYDRO-35
NATIONAL WEATHER SERVICE
— — DATA NOT AVAILABLE
MARYLAND STATE HIGHWAY ADMINISTRATION
SHA-61.1-403.0 4/78
I-2-A-29



RAINFALL INTENSITY FACTORS

FOR ALL FREQUENCY STORMS FROM
<u>0.0 MINUTES TO 10.0 MINUTES</u>
IN DURATION

THIS CHART WAS DERIVED FROM:
1. NOAA TECHNICAL MEMORANDUM NWS-HYDRO-35
NATIONAL WEATHER SERVICE



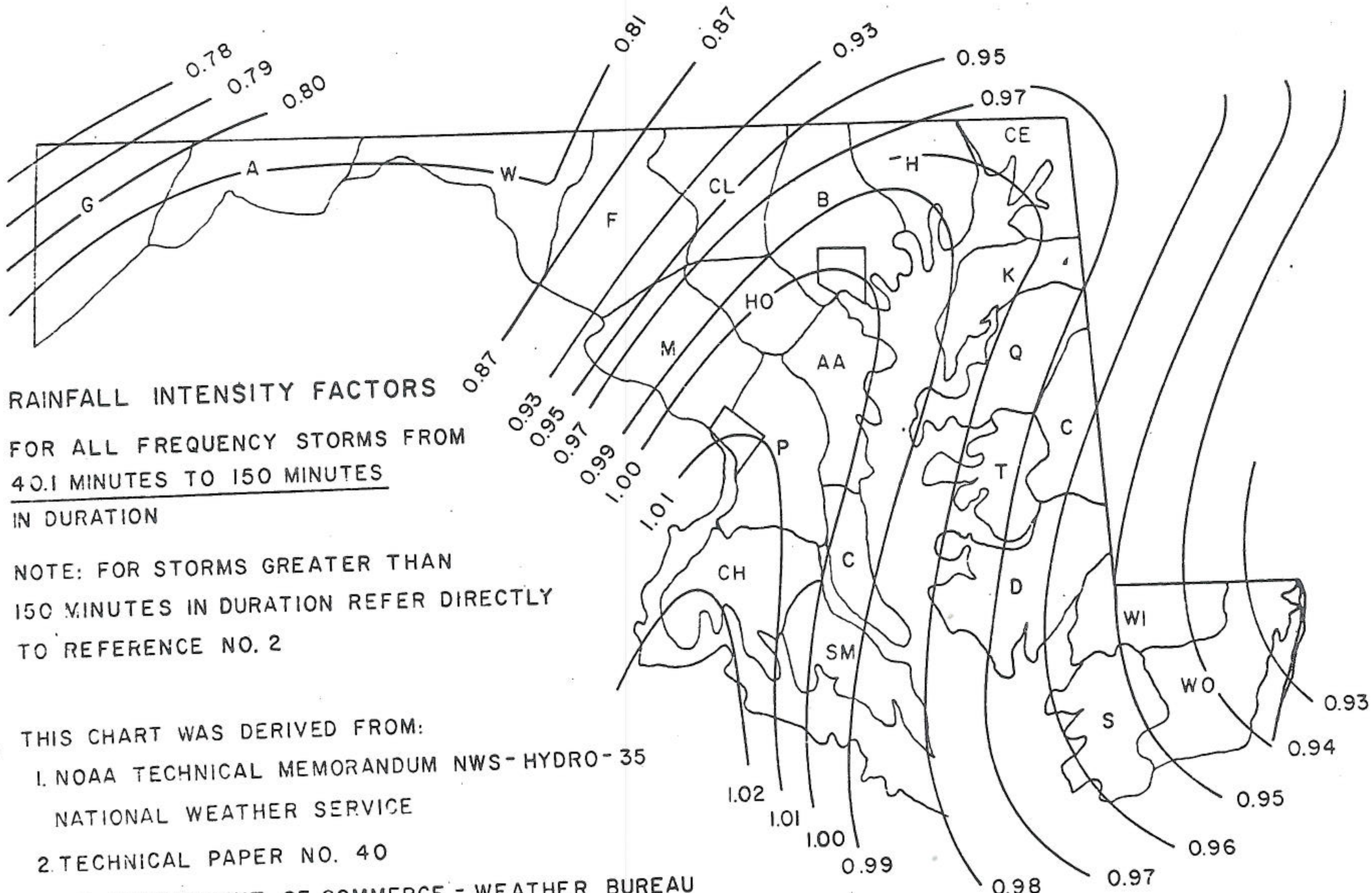
RAINFALL INTENSITY FACTORS

FOR ALL FREQUENCY STORMS FROM
10.1 MINUTES TO 40.0 MINUTES
IN DURATION

THIS CHART WAS DERIVED FROM:

1. NOAA TECHNICAL MEMORANDUM NWS-HYDRO-35
NATIONAL WEATHER SERVICE

MARYLAND STATE HIGHWAY ADMINISTRATION 4-78 SHA 61.1-403.2



RAINFALL INTENSITY FACTORS

FOR ALL FREQUENCY STORMS FROM
40.1 MINUTES TO 150 MINUTES
IN DURATION

NOTE: FOR STORMS GREATER THAN 150 MINUTES IN DURATION REFER DIRECTLY TO REFERENCE NO. 2

THIS CHART WAS DERIVED FROM:

1. NOAA TECHNICAL MEMORANDUM NWS-HYDRO-35
   NATIONAL WEATHER SERVICE
2. TECHNICAL PAPER NO. 40
   U.S. DEPARTMENT OF COMMERCE - WEATHER BUREAU

SHA 61.1 - 403.3

Appendix B
VDOT Hydraulic Design Advisory, HDA 05-03

HYDRAULIC DESIGN ADVISORY
HDA 05-03
DATE: JUNE 21, 2005

SUBJECT: VDOT's ADOPTION & IMPLEMENTATION OF NOAA ATLAS 14 RAINFALL PRECIPITATION FREQUENCY DATA

AUTHOR: D.M. LEGRANDE, SR.
ASST. STATE HYDRAULICS ENGINEER

The U.S. National Oceanic & Atmospheric Administration (NOAA) recently released their "ATLAS 14: RAINFALL PRECIPITATION FREQUENCY DATA" which covers the Ohio River basin and surrounding states (including Virginia). This information is most readily and conveniently accessed on NOAA's Internet web site at the following address: http://hdsc.nws.noaa.gov/hdsc/pfds/orb/va_pfds.html. This new data supercedes and replaces that which is contained in Technical Paper No. 40 "Rainfall frequency atlas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years" (Hershfield, 1961), NWS HYDRO-35 "Five- to 60-minute precipitation frequency for the eastern and central United States" (Frederick et al., 1977) and Technical Paper No. 49 "Two- to ten-day precipitation for return periods of 2 to 100 years in the contiguous United States" (Miller et al., 1964). All of the rainfall information currently contained in the "VDOT Drainage Manual" was predicated on TP-40 and/or HYDRO-35. All such information is no longer valid.

With the issuance of this Hydraulic Design Advisory, the Department officially recognizes and adopts the data presented in the "ATLAS 14" publication. Henceforth, the Department will require, subject to the guidelines described below, that its implementation of this data be employed for the design of all drainage facilities for which the hydrologic design is customarily predicated on rainfall data. This will include drainage designs for the Department's own facilities as well as those that may ultimately come under the Department's jurisdiction (subdivision streets, etc.). The Department recognizes that it will take some time before everyone becomes familiar with this new information and it can be fully and universally implemented. For this reason, it will be acceptable to continue to use the rainfall data currently in the "VDOT Drainage Manual" for projects under design that have completed the Public Hearing stage prior to the issuance of this Hydraulic Design Advisory.

In using the NOAA Internet web site, it should be noted that there occasionally will be more than one rainfall station located in or near a given county or city. The total point rainfall data displayed will, therefore, be dependent upon where one places the pointer used to make the selection. It is possible to get two or more different sets of total point rainfall data for the same county or city. To avoid confusion and to simplify the implementation and application of the new rainfall data, the Department has developed a set of "B, D, & E" factors for each county and major city throughout the state. These "B, D, & E" factors have been developed for 2, 5, 10, 25, 50, & 100-yr. recurrence interval storm durations. A tabulation of these factors accompanies this Hydraulic Design Advisory. A Microsoft EXCEL spreadsheet containing this same information and which will allow the data to be digitally transferred (i.e. copied and pasted) to other spreadsheets, software data files, etc. is also available for downloading via this web site. The spreadsheet is protected to preclude the possibility of inadvertently changing the data. These "B, D, & E" factors can be employed to determine rainfall intensity through the application of the following equation:

$I_f = B / (T_c + D)^E$

Where:

I_f = Rainfall intensity for a given recurrence interval "f", in inches/hour
T_c = Watershed time of concentration (assumed equal to the storm duration), in minutes

In situations where one must determine total point rainfall (as opposed to rainfall intensity) and time of concentration (or storm duration) is usually employed using hours (as opposed to minutes), the above equation can be modified as shown below:

$R_f = T_{c(h)} (B / (T_{c(m)} + D)^E)$

Where:

R_f = Total point rainfall for a given recurrence interval "f", in inches
$T_{c(h)}$ = Watershed time of concentration (assumed equal to the storm duration), in hours
$T_{c(m)}$ = Watershed time of concentration (assumed equal to the storm duration), in minutes

When employing the new "Atlas 14" rainfall precipitation frequency data, the Department's published "B, D, & E" factors shall be employed <u>exclusively</u> for the purposes of developing rainfall intensities and total point rainfall values. The use of the "IDF" (intensity-duration-frequency) and "RDF" (total point rainfall-duration-frequency) curves currently shown in the VDOT Drainage Manual shall be discontinued and they will be removed from the Manual at its next revision.

Regarding the impact of the implementation of the "Atlas 14" rainfall precipitation frequency data on computer software, the Department will no longer accept drainage designs from any software package that has not been predicated on this data, subject to the previously noted implementation period. It is our understanding, from communication with the FHWA, that the rainfall database contained in their popular "HYDRAIN" software suite will not be revised to reflect the "Atlas 14" data. The Department will, therefore, no longer accept any computations from the "HYDRAIN" suite that have been predicated on its current rainfall database, subject to the previously noted implementation period. As for software in current use by the Department, the latest version of the GEOPAK software package is being revised to include the "Atlas 14" based "B, D, & E" factors developed by the Department. Appropriate revisions will be distributed as soon as they are available. The following "written-in-house" programs have been revised to incorporate the "Atlas 14" data and the "B, D, & E" factors developed by the Department:

(1) "DISCHARGE" (for determining peak discharges using the Daniel G. Anderson & Franklin Snyder methods)
(2) "VIRTOC" (for determining rainfall intensity, time of concentration, and peak discharges using the Rational Formula)
(3) "RDDITCH" (for determining roadside and median ditch capacity and protective lining requirements)

These programs will be available to both Department and external users via the usual notification and distribution procedures. In addition to the above, new ".RND" (rainfall) files for all counties and major cities have been developed for use with the commercial "EAGLE POINT WATERSHED MODELING" (version

7.0SU-B) software package currently in use by the Department. These ".RND" files are available upon request, as their distribution should not be in violation of Eagle Point's copyright since one must have the program in order to use them.

Any comments or questions related to this Hydraulic Design Advisory should be directed to

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B. D. & E factors for determining rainfall intensity in the Rational and Modified Rational Methods (based on NOAA NW-14 Atlas data)

			2-YR			5-YR			10-YR			25-YR			50-YR			100-YR	
COUNTY/CITY	#	B	D	E	B	D	E	B	D	E	B	D	E	B	D	E	B	D	E
Arlington	00	52.73	11.25	0.83	50.63	10.50	0.77	45.98	9.25	0.72	41.35	7.75	0.66	38.56	7.00	0.61	32.29	5.00	0.55
Accomack	01	65.77	13.00	0.88	56.63	11.50	0.79	49.92	10.00	0.73	39.98	7.50	0.65	37.31	6.50	0.61	32.84	5.25	0.55
Albemarle	02	49.02	10.50	0.82	55.71	11.50	0.80	46.95	9.50	0.73	40.11	7.75	0.66	35.68	6.50	0.61	31.09	5.00	0.55
Alleghany	03	51.16	13.25	0.88	39.11	10.00	0.77	40.84	10.00	0.74	36.37	8.75	0.67	29.66	6.50	0.60	26.46	5.00	0.55
Amelila	04	59.23	12.25	0.86	55.73	11.25	0.79	47.70	9.50	0.73	40.73	7.75	0.66	36.22	6.50	0.61	33.29	5.75	0.56
Amherst	05	60.72	13.00	0.88	57.10	12.00	0.81	43.80	9.25	0.72	39.61	8.00	0.66	34.36	6.50	0.60	30.80	5.25	0.55
Appomattox	06	51.76	11.50	0.84	54.03	11.25	0.80	47.13	10.00	0.73	40.72	8.25	0.67	34.36	6.50	0.60	30.14	5.00	0.55
Augusta	07	46.46	12.25	0.85	44.03	10.75	0.79	41.63	10.00	0.74	32.39	7.25	0.64	32.48	7.25	0.62	27.18	5.25	0.55
Bath	08	46.46	12.25	0.85	47.91	11.50	0.80	38.95	9.50	0.72	34.24	7.75	0.66	30.19	6.25	0.60	28.05	5.50	0.56
Bedford	09	47.85	11.25	0.83	48.76	10.75	0.78	45.55	10.00	0.73	40.49	8.50	0.67	33.51	6.50	0.60	29.36	5.00	0.55
Bland	10	36.34	10.00	0.81	41.14	10.75	0.78	38.52	9.75	0.73	32.99	7.75	0.66	29.71	6.50	0.60	26.71	5.25	0.55
Botetourt	11	51.98	12.25	0.85	51.47	11.50	0.80	44.82	9.75	0.73	36.34	7.50	0.65	33.51	6.50	0.60	29.23	5.00	0.55
Bristol	102	41.68	11.50	0.83	41.14	10.75	0.78	42.11	10.75	0.75	31.43	7.75	0.65	27.32	6.00	0.59	26.45	5.50	0.56
Brunswick	12	62.82	12.25	0.85	55.69	10.50	0.78	49.74	9.25	0.72	41.54	7.25	0.65	40.85	7.00	0.62	33.99	5.00	0.55
Buchanan	13	46.78	11.50	0.85	51.34	12.25	0.82	41.75	9.75	0.74	34.41	7.25	0.65	31.36	6.00	0.60	29.24	5.00	0.56
Buckingham	14	54.24	11.50	0.85	54.80	11.50	0.80	44.53	9.25	0.72	39.48	7.75	0.66	33.09	6.00	0.59	30.63	5.25	0.55
Campbell	15	46.46	12.25	0.85	44.03	10.75	0.79	41.63	10.00	0.74	32.39	7.25	0.64	32.48	7.25	0.62	27.18	5.25	0.55
Caroline	16	65.88	12.75	0.88	58.28	11.50	0.80	51.24	10.00	0.74	39.77	7.25	0.65	36.12	6.25	0.60	32.97	5.25	0.55
Carroll	17	54.24	11.50	0.85	52.48	10.75	0.79	48.34	10.00	0.74	38.91	7.75	0.65	35.14	6.50	0.61	30.77	5.00	0.55
Charles City	18	61.04	11.50	0.85	55.05	10.50	0.77	52.12	9.75	0.73	42.40	7.50	0.65	39.29	6.50	0.61	34.58	5.00	0.55
Charlotte	19	59.23	12.25	0.86	56.63	11.50	0.79	53.27	10.50	0.75	40.16	7.75	0.65	36.03	6.50	0.60	31.51	5.00	0.55
Charlottesville (city)	104	49.02	10.50	0.82	55.71	11.50	0.80	46.95	9.50	0.73	40.11	7.75	0.66	35.68	6.50	0.61	31.09	5.00	0.55
Chesapeake (city)	131	78.62	13.00	0.88	74.36	12.25	0.81	56.41	9.25	0.72	51.18	8.25	0.66	46.33	7.00	0.62	39.60	5.25	0.56
Chesterfield	20	52.72	10.75	0.83	49.08	9.75	0.76	50.71	10.00	0.73	39.77	7.25	0.65	37.31	6.50	0.61	32.29	5.00	0.55
Clarke	21	41.52	8.75	0.82	47.08	9.00	0.80	41.34	7.25	0.73	37.79	5.75	0.67	36.75	5.00	0.64	34.34	4.00	0.59
Craig	22	44.29	11.50	0.84	41.60	10.50	0.77	43.45	10.50	0.75	34.24	7.75	0.66	32.48	7.25	0.62	28.23	5.50	0.56
Culpeper	23	58.30	12.25	0.86	56.46	11.50	0.80	45.25	9.25	0.72	42.03	8.25	0.67	34.33	6.00	0.59	32.38	5.25	0.56
Cumberland	24	60.86	12.75	0.87	56.46	11.50	0.80	46.95	9.50	0.73	36.73	7.00	0.64	33.82	6.00	0.59	32.07	5.50	0.56
Danville (city)	108	50.48	10.50	0.82	39.15	8.75	0.72	35.48	7.75	0.66	33.76	6.75	0.62	33.66	6.25	0.59	34.46	6.00	0.57
Dickenson	25	53.26	12.75	0.87	44.86	10.75	0.79	44.28	10.50	0.75	35.17	7.75	0.65	35.11	7.25	0.62	29.39	5.00	0.55
Dinwiddie	26	61.04	11.50	0.85	57.21	10.75	0.78	54.03	10.00	0.74	44.17	7.75	0.66	40.85	7.00	0.62	34.12	5.00	0.55
Essex	28	61.14	12.00	0.86	59.79	11.50	0.80	51.93	10.00	0.74	41.19	7.50	0.65	40.52	7.25	0.62	33.95	5.25	0.56
Fairfax	29	55.09	11.50	0.84	54.20	11.00	0.79	47.70	9.50	0.73	39.18	7.25	0.65	36.34	6.50	0.60	32.29	5.00	0.55
Fauquier	30	54.24	11.50	0.85	54.80	11.50	0.80	48.34	10.00	0.74	41.03	8.25	0.66	35.44	6.50	0.60	31.38	5.00	0.55
Floyd	31	60.86	12.75	0.87	53.32	10.75	0.79	46.45	9.25	0.72	40.41	7.75	0.65	38.96	7.25	0.62	32.00	5.00	0.55
Fluvanna	32	60.98	12.75	0.88	51.10	10.75	0.79	47.55	10.00	0.74	38.60	7.75	0.65	34.59	6.50	0.61	30.33	5.25	0.55

B. D. & E factors for Virginia for determining rainfall intensity in the Rational and Modified Rational Methods (based on NOAA NW-14 Atlas data)

			2-YR			5-YR			10-YR			25-YR			50-YR			100-YR	
COUNTY/CITY	#	B	D	E	B	D	E	B	D	E	B	D	E	B	D	E	B	D	E
Franklin	33	54.24	11.50	0.85	52.48	10.75	0.79	48.34	10.00	0.74	38.91	7.75	0.65	35.14	6.50	0.61	30.77	5.00	0.55
Frederick	34	44.35	9.50	0.84	45.41	8.50	0.79	43.33	7.75	0.75	37.02	5.75	0.67	35.19	4.75	0.63	33.81	3.75	0.59
Fredericksburg (city)	111	65.52	13.25	0.88	60.63	12.00	0.81	49.92	10.00	0.73	41.35	7.75	0.66	38.56	7.00	0.61	30.46	4.50	0.54
Giles	35	48.45	12.25	0.87	47.31	12.00	0.81	38.52	9.75	0.73	34.13	8.25	0.67	28.63	6.50	0.60	26.45	5.50	0.56
Gloucester	36	60.97	11.50	0.84	60.74	11.25	0.79	53.07	9.50	0.73	43.62	7.50	0.65	40.14	6.50	0.60	35.98	5.25	0.55
Goochland	37	59.23	12.25	0.86	55.73	11.25	0.79	47.70	9.50	0.73	40.73	7.75	0.66	36.22	6.50	0.61	31.51	5.00	0.55
Grayson	38	43.44	11.50	0.84	47.31	12.00	0.81	38.69	9.50	0.73	33.62	7.75	0.66	32.48	7.25	0.62	27.65	5.25	0.55
Greene	39	46.81	10.50	0.82	57.10	12.00	0.81	48.11	10.00	0.74	38.01	7.25	0.65	34.64	6.25	0.61	31.75	5.25	0.56
Greensville	40	56.78	11.25	0.84	55.17	10.75	0.78	52.82	10.00	0.74	41.80	7.50	0.65	38.93	6.50	0.61	34.24	5.25	0.55
Halifax	41	62.13	12.25	0.87	54.16	10.75	0.78	49.92	10.00	0.73	42.69	8.25	0.67	36.22	6.50	0.61	31.60	5.25	0.55
Hampton (city)	114	64.31	11.50	0.85	64.94	11.50	0.80	57.19	10.00	0.74	44.49	7.25	0.64	41.77	6.50	0.60	37.02	5.00	0.55
Hanover	42	55.94	11.50	0.84	53.49	10.75	0.78	47.18	9.25	0.72	39.98	7.50	0.65	36.53	6.50	0.60	32.68	5.25	0.56
Harrisonburg (city)	115	43.01	11.25	0.84	44.71	10.50	0.80	39.71	9.25	0.74	32.17	6.50	0.65	28.85	5.25	0.60	28.34	4.75	0.57
Henrico	43	55.94	11.50	0.84	53.49	10.75	0.78	47.18	9.25	0.72	39.98	7.50	0.65	36.53	6.50	0.60	32.68	5.25	0.56
Henry	44	52.73	11.25	0.83	50.63	10.50	0.77	46.45	9.25	0.72	38.59	7.25	0.65	35.26	6.50	0.60	31.09	5.00	0.55
Highland	45	36.67	10.00	0.81	34.94	8.93	0.74	34.82	8.46	0.71	32.93	7.09	0.66	33.21	6.98	0.64	29.31	6.40	0.59
Isle of Wight	46	71.07	12.25	0.86	65.58	11.25	0.79	54.11	9.25	0.72	47.20	7.50	0.65	46.41	7.25	0.62	38.84	5.25	0.56
James City	47	70.63	12.75	0.87	57.84	10.50	0.78	55.61	10.00	0.74	48.54	8.50	0.67	38.78	6.00	0.59	36.77	5.25	0.56
King George	48	62.71	12.75	0.87	54.16	10.75	0.78	48.93	9.50	0.73	43.35	8.25	0.67	36.12	6.25	0.60	32.92	5.00	0.55
King & Queen	49	65.74	12.75	0.87	49.83	9.75	0.76	*50.43*	9.50	0.73	44.67	8.25	0.66	37.20	6.25	0.60	32.80	4.75	0.55
King William	50	62.90	12.25	0.86	51.80	10.00	0.77	51.51	10.00	0.73	41.19	7.50	0.65	40.52	7.25	0.62	33.21	5.00	0.55
Lancaster	51	60.12	11.50	0.84	61.61	11.50	0.80	53.83	9.75	0.74	44.47	7.75	0.66	39.83	6.50	0.61	35.83	5.25	0.56
Lee	52	51.05	12.25	0.86	45.70	10.75	0.78	38.28	8.75	0.71	38.78	8.50	0.67	34.62	6.75	0.61	31.95	5.75	0.56
Lexington (city)	117	44.29	11.50	0.84	46.49	11.50	0.79	39.05	9.25	0.72	33.28	7.25	0.65	33.34	7.25	0.62	27.07	5.00	0.55
Loudoun	53	61.40	12.25	0.88	44.34	8.75	0.76	46.93	8.75	0.74	41.48	7.25	0.67	36.12	5.50	0.61	33.25	4.50	0.56
Louisa	54	60.86	12.75	0.87	61.41	12.25	0.82	45.25	9.25	0.72	40.11	7.75	0.66	35.68	6.50	0.61	31.05	5.00	0.55
Lunenburg	55	60.15	12.25	0.85	49.08	9.75	0.76	50.71	10.00	0.73	39.77	7.25	0.65	39.34	7.25	0.62	32.50	5.25	0.55
Lynchburg (city)	118	46.46	12.25	0.85	44.03	10.75	0.79	41.63	10.00	0.74	32.39	7.25	0.64	32.48	7.25	0.62	27.18	5.25	0.55
Madison	56	54.24	11.50	0.85	53.17	10.75	0.79	46.61	9.25	0.73	41.85	8.00	0.67	37.33	6.50	0.62	33.01	5.25	0.57
Martinsville (city)	120	52.73	11.25	0.83	50.63	10.50	0.77	46.45	9.25	0.72	38.59	7.25	0.65	35.26	6.50	0.60	31.09	5.00	0.55
Mathews	57	65.67	12.25	0.86	58.83	10.75	0.78	52.39	9.25	0.72	48.24	8.25	0.67	40.45	6.50	0.60	37.10	5.25	0.56
Mecklenburg	58	60.15	12.25	0.85	49.08	9.75	0.76	50.71	10.00	0.73	39.77	7.25	0.65	39.34	7.25	0.62	32.50	5.25	0.55
Middlesex	59	72.66	13.25	0.88	61.46	11.25	0.79	52.39	9.75	0.73	45.09	7.75	0.66	40.37	6.50	0.61	36.12	5.25	0.56
Montgomery	60	47.29	11.75	0.85	44.20	10.75	0.78	44.28	10.50	0.75	35.12	7.75	0.66	33.34	7.25	0.62	27.24	5.00	0.55
Nelson	62	51.90	11.25	0.84	49.81	10.50	0.77	45.25	9.25	0.72	38.59	7.25	0.65	36.22	6.50	0.61	32.21	5.25	0.56
New Kent	63	62.82	12.25	0.85	55.69	10.50	0.78	49.27	9.25	0.72	43.85	7.75	0.66	41.70	7.25	0.62	34.75	5.25	0.55

B. D. & E factors for Virginia for determining rainfall intensity in the Rational and Modified Rational Methods (based on NOAA NW-14 Atlas data)

			2-YR			5-YR			10-YR			25-YR			50-YR			100-YR	
COUNTY/CITY	#	B	D	E	B	D	E	B	D	E	B	D	E	B	D	E	B	D	E
Newport News (city)	121	64.31	11.50	0.85	64.94	11.50	0.80	57.19	10.00	0.74	44.49	7.25	0.64	41.77	6.50	0.60	37.02	5.00	0.55
Norfolk (city)	122	60.83	11.25	0.84	64.03	11.50	0.80	51.92	9.25	0.72	47.96	8.25	0.66	39.29	6.00	0.59	37.10	5.25	0.56
Northampton	65	61.14	12.00	0.86	51.80	10.00	0.77	50.43	9.50	0.73	41.80	7.50	0.65	40.85	7.00	0.62	34.58	5.25	0.55
Northumberland	66	59.28	11.50	0.85	60.70	11.50	0.80	52.30	10.00	0.73	44.98	8.25	0.66	41.70	7.25	0.62	34.58	5.25	0.55
Nottoway	67	62.14	12.00	0.86	55.67	10.75	0.79	53.53	10.50	0.75	39.77	7.25	0.65	36.11	6.25	0.60	32.50	5.25	0.55
Orange	68	58.30	12.25	0.86	49.81	10.50	0.77	46.95	9.50	0.73	40.11	7.75	0.66	35.68	6.50	0.61	30.10	4.75	0.54
Page	69	39.07	8.50	0.82	41.80	8.25	0.78	40.62	7.50	0.74	38.83	6.50	0.68	32.66	4.50	0.62	34.36	4.50	0.60
Patrick	70	69.66	12.75	0.87	58.05	10.75	0.78	50.00	9.25	0.72	44.80	7.75	0.66	39.29	6.50	0.61	34.89	5.25	0.56
Pittsylvania	71	50.48	10.50	0.82	39.15	8.75	0.72	35.48	7.75	0.66	33.76	6.75	0.62	33.66	6.25	0.59	34.46	6.00	0.57
Powhatan	72	55.09	11.50	0.84	53.32	10.75	0.79	49.13	10.00	0.74	42.03	8.25	0.67	37.41	7.00	0.61	32.74	5.50	0.56
Prince Edward	73	42.34	9.75	0.78	54.20	11.00	0.79	48.19	9.50	0.73	40.73	7.75	0.66	34.33	6.00	0.59	31.56	5.25	0.55
Prince George	74	60.12	11.50	0.84	62.36	11.50	0.80	53.51	10.00	0.74	42.40	7.50	0.65	37.20	6.00	0.59	34.71	5.25	0.55
Prince William	76	52.66	11.50	0.85	46.85	10.00	0.77	47.55	10.00	0.74	40.37	8.25	0.66	35.14	6.50	0.61	31.09	5.25	0.55
Pulaski	77	45.53	12.25	0.86	47.31	12.00	0.81	34.60	8.50	0.71	34.79	8.25	0.67	28.35	6.00	0.59	26.38	5.25	0.55
Rappahannock	78	60.32	12.25	0.87	49.28	9.75	0.78	48.73	9.25	0.74	40.59	7.25	0.66	38.67	6.50	0.62	33.55	4.75	0.56
Richmond	79	62.90	12.25	0.86	59.05	11.50	0.80	53.81	10.00	0.74	44.32	8.25	0.66	39.21	6.75	0.61	34.42	5.25	0.56
Richmond (city)	127	57.69	11.50	0.85	54.99	10.75	0.78	47.91	9.25	0.72	41.66	7.75	0.65	36.88	6.50	0.60	33.15	5.25	0.56
Roanoke	80	47.62	11.50	0.85	47.08	10.75	0.79	47.73	10.75	0.75	38.78	8.50	0.67	34.84	7.25	0.62	29.06	5.25	0.55
Roanoke (city)	128	47.62	11.50	0.85	47.08	10.75	0.79	47.73	10.75	0.75	38.78	8.50	0.67	34.84	7.25	0.62	29.06	5.25	0.55
Rockbridge	81	44.29	11.50	0.84	46.49	11.50	0.79	39.05	9.25	0.72	33.28	7.25	0.65	33.34	7.25	0.62	27.07	5.00	0.55
Rockingham	82	43.01	11.25	0.84	44.71	10.50	0.80	39.71	9.25	0.74	32.17	6.50	0.65	28.85	5.25	0.60	28.34	4.75	0.57
Russell	83	46.78	11.50	0.85	43.36	10.75	0.78	38.95	9.50	0.72	37.76	8.75	0.67	31.10	6.50	0.60	28.76	5.25	0.56
Scott	84	51.20	12.75	0.87	52.43	12.75	0.82	42.17	10.00	0.74	35.47	8.00	0.66	33.34	7.25	0.62	28.29	5.25	0.56
Shenandoah	85	45.21	9.25	0.85	44.82	8.50	0.80	43.22	7.75	0.75	39.74	6.25	0.69	35.16	4.75	0.64	32.71	3.50	0.59
Smyth	86	52.17	12.75	0.87	44.20	10.75	0.78	46.01	10.75	0.75	36.42	8.25	0.66	34.52	7.25	0.62	29.06	5.25	0.55
Southampton	87	67.40	12.25	0.86	65.69	11.50	0.80	54.56	9.50	0.73	44.83	7.50	0.65	41.23	6.50	0.60	38.91	5.75	0.57
Spotsylvania	88	65.52	13.25	0.88	60.63	12.00	0.81	49.92	10.00	0.73	41.35	7.75	0.66	38.56	7.00	0.61	30.46	4.50	0.54
Stafford	89	65.52	13.25	0.88	60.63	12.00	0.81	49.92	10.00	0.73	41.35	7.75	0.66	38.56	7.00	0.61	30.46	4.50	0.54
Staunton (city)	132	46.46	12.25	0.85	44.03	10.75	0.79	41.63	10.00	0.74	32.39	7.25	0.64	32.48	7.25	0.62	27.18	5.25	0.55
Suffolk (city)	133	78.09	12.81	0.88	60.79	10.45	0.77	54.21	9.02	0.72	47.94	7.41	0.65	45.23	6.47	0.62	42.16	5.42	0.58
Surry	90	63.47	11.50	0.85	58.83	10.75	0.78	52.39	9.25	0.72	45.72	7.75	0.66	40.68	6.50	0.60	36.45	5.25	0.55
Sussex	91	60.01	11.25	0.84	78.66	13.25	0.85	54.30	10.00	0.73	46.30	8.25	0.66	42.87	7.25	0.62	35.65	5.25	0.55
Tazewell	92	44.30	12.00	0.85	47.70	12.25	0.82	36.89	9.25	0.73	34.19	8.00	0.66	29.66	6.25	0.60	27.24	5.00	0.55
Virginia Beach (city)	134	61.66	11.25	0.84	61.78	10.75	0.79	56.67	10.00	0.73	49.63	8.25	0.67	40.32	6.00	0.59	37.86	5.25	0.56
Warren	93	44.97	9.50	0.84	44.54	8.75	0.78	41.57	7.75	0.73	39.56	6.50	0.68	33.97	4.75	0.61	34.11	4.25	0.59
Washington	95	41.68	11.50	0.83	41.14	10.75	0.78	42.11	10.75	0.75	31.43	7.75	0.65	27.32	6.00	0.59	26.45	5.50	0.56

B. D. & E factors for Virginia for determining rainfall intensity in the Rational and Modified Rational Methods (based on NOAA NW-14 Atlas data}

			2-YR			5-YR			10-YR			25-YR			50-YR			100-YR	
COUNTY/CITY	#	B	D	E	B	D	E	B	D	E	B	D	E	B	D	E	B	D	E
Westmoreland	96	55.94	11.50	0.84	58.28	11.50	0.80	54.10	10.50	0.75	41.98	7.75	0.66	39.93	7.25	0.62	33.44	5.25	0.55
Williamsburg (city)	137	70.63	12.75	0.87	57.84	10.50	0.78	55.61	10.00	0.74	48.54	8.50	0.67	38.78	6.00	0.59	36.77	5.25	0.56
Winchester (city)	138	44.35	9.50	0.84	45.41	8.50	0.79	43.33	7.75	0.75	37.02	5.75	0.67	35.19	4.75	0.63	33.81	3.75	0.59
Wise	97	53.26	12.75	0.87	44.86	10.75	0.79	44.28	10.50	0.75	36.41	8.00	0.66	35.11	7.25	0.62	29.23	5.00	0.55
Wythe	98	50.79	13.00	0.88	44.18	11.25	0.80	42.97	10.75	0.75	35.80	8.25	0.67	31.03	6.50	0.61	28.29	5.25	0.56
York	99	69.54	12.75	0.87	58.89	10.75	0.78	55.09	10.00	0.73	45.72	7.75	0.66	40.68	6.50	0.60	38.41	5.75	0.57